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A COMPARISON OF PREDICTED PROPERTY LINE PARTICULATE CONCENTRATIONS USING ISCST3, AERMOD, WINDTRAX, AND AUSTAL VIEW

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Abstract

ISCST3 has been the preferred model of the Environmental Protection Agency (EPA) to estimate concentrations of particulate matter (PM) at or beyond the property line of sources emitting PM such as cotton gins. The modeled concentrations can be used to limit emissions from stationary and fugitive sources. The regulatory limits of PM include limits for PM_{10}, $PM_{2.5}$, and coarse PM (PM_{coarse}). Beginning in November 2006, the EPA will begin transitioning to the use of AERMOD for predicting concentrations on the basis that AERMOD more accurately characterizes the planetary boundary layer. Both AERMOD and ISCST3 use a Gaussian plume model to predict concentrations, but AERMOD has a more detailed set of meteorological inputs. The dispersion modeling program chosen by EPA to predict property line concentrations will have a direct effect on the cotton ginning industry. Each model may yield different results. Inaccurate predictions of property line concentrations for cotton gins could result in the unjust denial of air quality permits. It is important that the predicted downwind concentrations using ISCST3 and AERMOD be evaluated relative to appropriate regulations of the cotton ginning industry.

Introduction

The Environmental Protection Agency (EPA) has used dispersion models to predict the concentrations of pollutants at or beyond the property line of a pollution source. The modeled concentrations can be utilized in limiting emissions from stationary and fugitive sources. The EPA has set National Ambient Air Quality Standards (NAAQS) for criteria pollutants, including particulate matter (PM). Currently, there are NAAQS for two classifications of PM: PM with an aerodynamic equivalent diameter (AED) of 10 microns or less is classified as PM_{10}, while PM with an AED of 2.5 microns or less is classified as $PM_{2.5}$ or PM_{fine}. According to the Federal Clean Air Act (CAA), primary and secondary NAAQS are requisite to protect the public health and welfare and may be revised in the same manner as promulgated. Currently, 24-hour NAAQS for PM_{fine} and PM_{10} are 65 $\mu g/m^3$ and 150 $\mu g/m^3$, respectively. EPA is proposing to make revisions to the primary and secondary NAAQS for PM. It is being proposed that the 24-hour $PM_{2.5}$ standard be revised to 35 $\mu g/m^3$, thereby providing increased protection against health effects associated with short-term exposure (EPA, 2005). The 24-hour PM_{10} standard will also be revised by establishing a new indicator for thoracic coarse particles, or particles between 2.5 and 10 µm in diameter ($PM_{10-2.5}$ or PM_{coarse}). "EPA also proposes that agricultural sources, mining sources, and other similar sources of crustal material shall not be subject to control in meeting the proposed standard" (EPA, 2005). The NAAQS for the new PM_{coarse} will likely be set at 70 $\mu g/m^3$. Also, upon finalization of a primary 24-hour standard for $PM_{10-2.5}$, EPA proposes to revoke the current PM_{10} standard in all areas of the country except those in which there is at least one monitor located in an urbanized area that violates the current 24-hour PM_{10} standard based on recent data (EPA, 2005). "With regard to secondary PM standards, EPA proposes to revise the current standards by making them identical to the suite of proposed primary standards for fine and coarse particles, providing protection against PM-related public welfare effects including visibility impairment, effects on vegetation and ecosystems, and materials and soiling" (EPA, 2005). Previous research by Texas A&M University indicates that agricultural dusts have very small amounts of PM_{fine}. This implies that, for agricultural sources, PM_{coarse} concentrations will be similar to PM_{10} concentrations, so agricultural sources that exceed, or are predicted to exceed, the NAAQS for PM_{10} will likely exceed the proposed NAAQS for PM_{coarse}. It is important to note that these revisions are still in the proposal process and have not been finalized.

According to the CAA, each state shall, after the promulgation of a NAAQS, adopt and submit a plan which provides for implementation, maintenance, and enforcement of such a standard in each air quality control region within the state. Each state implementation plan (SIP) shall include enforceable emission limitations and other control measures, means, or techniques, schedules, and timetables for compliance, as may be necessary to meet the applicable requirements of the CAA. Each SIP should also provide for establishment and operation to monitor, compile, and analyze data on ambient air quality. A program will be included to provide for the enforcement of the previously described measures and the "regulation of the areas covered by the plan as necessary to assure that national ambient air quality standards are achieved" (Clean Air Act, 1997). The SIP should also contain adequate provisions prohibiting any source from emitting any air pollutant in amounts which will "contribute significantly to non-attainment in… any such national primary or secondary ambient air quality standard, or interfere with measures required to be included in the applicable implementation plan… to prevent significant deterioration of air quality or to protect visibility" (Clean Air Act, 1997).

EPA requires states to use dispersion models for air quality planning and to develop a SIP for most areas that are not in compliance with NAAQS, or classified as "non-attainment." Currently, EPA uses Industrial Source Complex Short Term Version 3 (ISCST3) as the dispersion model to predict pollutant concentrations. However, EPA is propagating the use of AERMOD-PRIME (AERMOD) to replace ISCST3 as the dispersion model of choice as of November 9, 2006. There will be a one year transition period where ISCST3 will still be accepted, but as of late 2007, ISCST3 will no longer be a valid model (Federal Register, 2005). It is argued that AERMOD better characterizes pollutant dispersion within the planetary boundary layer, thus leading to more accurate predictions of downwind pollutant concentrations from stationary and fugitive sources.

This research compares the predicted PM_{10} concentrations at and beyond the property line of a Texas cotton gin using ISCST3 with Plume Rise Model Enhancements (PRIME) and AERMOD-PRIME.

ISCST3-PRIME

ISCST3, a steady-state double Gaussian plume dispersion model "recommended by the EPA for industrial sources, rural or urban areas, flat or rolling terrain, transport distances less than 50 kilometers, one-hour to annual averaging times, and continuous toxic emissions" (Trinity Consultants, 2000). For the purpose of this research, ISCST3 was used in collaboration with PRIME. PRIME is used to better characterize dispersion around buildings (Federal Register, 2005). Using PRIME for this study was appropriate since emission concentrations were modeled for a cotton gin facility, which includes several stationary point sources situated amongst several structures of various sizes and shapes. ISCST3 models horizontal and vertical pollutant concentration distributions based on Pasquill-Gifford vertical and horizontal plume spread parameters (Cooper and Alley, 2002).

AERMOD-PRIME

"AERMOD is a best state-of-the-practice Gaussian plume dispersion model whose formulation is based on planetary boundary layer principles" (Federal Register, 2005). According to the EPA, AERMOD characterizes plume dispersion better than ISCST3. AERMOD is suited for "assessment of plume impacts from stationary sources in simple, intermediate, and complex terrain for *other than* downwash and deposition applications" (Federal Register, 2005). For this reason, AERMOD was also used in collaboration with PRIME. AERMOD integrates more meteorological data into the model than ISCST3. Appendix A compares the required model inputs and the meteorological processing for ISCST3 and AERMOD.

It is important to note that AERMOD results can vary significantly depending on the values of meteorological inputs. Table 1 compares concentrations predicted by AERMOD for an area source. Values for the surface roughness factor, Albedo, and Bowen ratio were varied, while all other inputs remained constant. Minimum and maximum values for these factors were found on the TCEQ website.

The concentrations were compared by taking the ratio of the case-specific predicted concentration and the minimum predicted concentration from all the cases.

Table 1. Ratios of predicted concentrations when varying surface roughness, Albedo, and Bowen ratio.

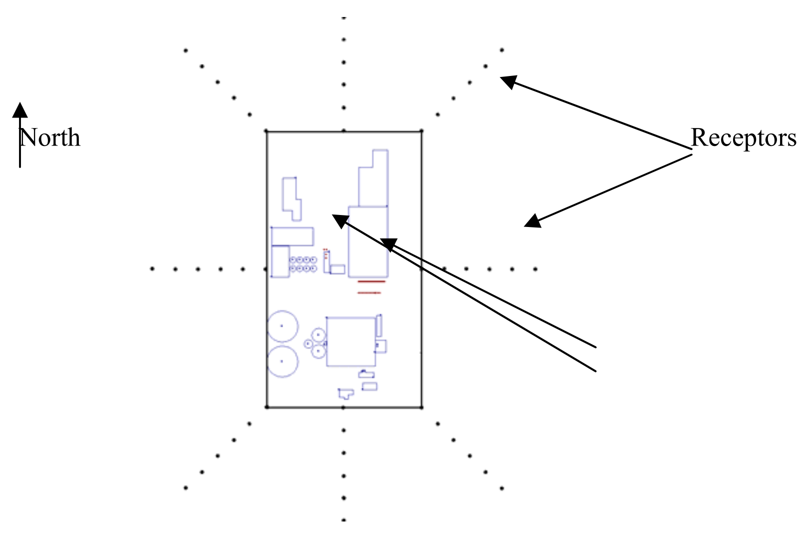
Surface Roughness (m)	Albedo	Bowen	Predicted Conc. / Minimum Predicted Conc.
1.5	0.45	5	1.11
1.5	0.45	0.2	1.11
1.5	0.1	5	1.00
1.5	0.1	0.2	1.00
0.001	0.45	5	13.00
0.001	0.45	0.2	13.00
0.001	0.1	5	11.98
0.001	0.1	0.2	11.98

As seen in Table 1, the variation in modeled concentrations with changes in surface roughness is staggering. The surface roughness factor has, by far, the most significant impact on modeled results, while the Bowen ratio has no effect. Changes in Albedo have some effect, though much less than surface roughness.

Methods

Predicted concentrations of PM_{10} at and beyond the property line were modeled for a Texas cotton gin. Daily concentrations were predicted for seven days using weather data from the Texas High Plains for the first week of November 1988, assuming the recommended surface roughness factor (0.05 m) for the surrounding area. The AP-42 emission rate for PM_{10} of 1.2 #/bale was used for a thirty bale per hour (bph) gin.

For both ISCST3 and AERMOD, receptors were placed every twenty meters starting at the property line and continuing up to 100 meters from the property line in eight directions- north, northeast, east, southeast, south, southwest, west, and northwest. The gin layout with sources, buildings, and receptors can be seen in Figure 1 below:



Sources

Figure 1. Gin Layout

Results

Predicted twenty-four hour concentrations were compiled for seven days for forty-eight receptors. The relationship between ISCST3 and AERMOD was found using the ratio of the predicted concentration for each model at a particular receptor. The ratios were found using the equation below:

(1) $$R = \frac{\text{Predicted AERMOD Concentration}}{\text{Predicted ISCST3 Concentration}}$$

The ratio became unreasonably high in situations where ISCST3 predicted concentrations below two $\mu g/m^3$. A distribution of the ratios of modeled concentrations is shown in Table 2.

Table 2. Distribution of Ratios of Predicted Concentrations for AERMOD and ISCST3.

Ratio of Predicted Concentrations for AERMOD and ISCST3							
	$R \leq 1$	$1 < R \leq 1.5$	$1.5 < R \leq 2$	$2 < R \leq 3$	$3 < R \leq 4$	$R > 4$	Total
Frequency	3	97	42	14	1	0	157
Percent	1.9	61.8	26.8	8.9	0.6	0.0	

R = Predicted AERMOD Concentration / Predicted ISCST3 Concentration

All ISCST3 concentrations >2 ug/m3 are included.

The mean value for R was found to be 1.5, which means that, on average, AERMOD will predict a concentration one and a half times larger than ISCST3. R values tended to increase as receptor distance from the property line increased. Table 3 shows the effective downwind concentration ratios for the week.

Table 3. Effective Downwind Concentration Ratios

Distance from property line (m)	1-Nov	2-Nov	3-Nov	4-Nov	5-Nov	6-Nov	7-Nov
0	1.1	1.0	1.0	1.1	1.2	1.0	1.2
20	1.1	1.1	1.0	1.2	1.3	1.1	1.3
40	1.1	1.2	1.0	1.2	1.3	1.2	1.4
60	1.5	1.3	1.1	1.2	1.4	1.5	1.4
80	3.2	1.4	1.1	1.2	1.4	1.7	1.5
100	5.7	1.6	1.1	1.2	1.4	2.0	1.5

Figure 2 further illustrates this trend.

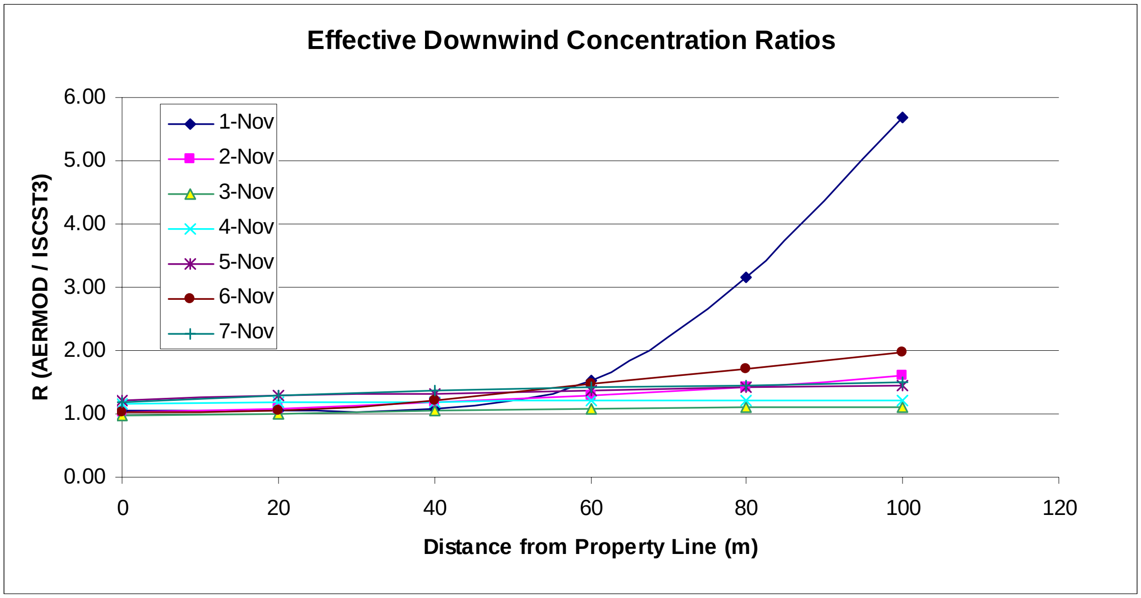


Figure 2. Effective Downwind Concentration Ratios

Since both ISCST3 and AERMOD are linear models [i.e. there is a direct relationship between emission concentrations and downwind concentrations], it is expected that the ratio of the concentrations will remain the same as the emission rate increases.

Conclusions

For the case of this cotton gin, AERMOD predicts PM_{10} concentrations at and beyond the property line 1.5 times larger than does ISCST3. With the transfer from ISCST3 to AERMOD as the EPA approved dispersion model, point sources that once were considered to be in compliance may no longer be. For example, a gin that was given a permit based on the ISCST3 prediction that downwind PM_{10} concentrations at the property line would be 120 $\mu g/m^3$, would now be predicted to have a downwind concentration of 180 $\mu g/m^3$ according to AERMOD, assuming the emission factor for PM_{10} in the state remained unchanged. This new modeled concentration is above the NAAQS. If the state uses NAAQS as the property line concentration limit, the pollutant source would exceed the permissible concentration level. In order for the source to stay within the permitted level, emission controls would need to be incorporated to lower the source PM_{10} emission rate, thereby reducing the property line concentrations. It is imperative to note that the AERMOD/ISCST3 ratio of 1.5 is case specific, so a different gin layout could yield a different model relationship. Further research should be done for various point sources to better capture the relationship between AERMOD and ISCST3. More extensive research should also be carried out in order to further analyze the effect on predicted AERMOD concentrations caused by varying AERMOD input parameters.

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Appendix A

Comparison of Dispersion Model Features- ISCST3 vs. AERMOD

Feature	ISCST3	AERMOD	Comments
Types of sources modeled	Point, area, and volume sources	Same as ISCST3	Models are comparable
Plume Rise	Uses Briggs equations with stack-top wind speed and vertical temperature gradient	In stable conditions, it uses Briggs equations with winds and temperature gradient at stack top and half-way to final plume rise; in convective conditions, plume rise is superimposed on the displacements caused by random convective velocities	AERMOD is better because in stable conditions, it factors in wind and temperature changes above stack top, and in unstable conditions, it accounts for convective updrafts and downdrafts
Meteorological Data Input	One level of data used even if multiple levels of data are available	Multiple levels of data can be utilized by the model	AERMOD can adapt multiple levels of data to various stack and plume heights
Profiling Meteorological Data	Only wind speed is profiled	AERMOD creates profiles of wind, temperature, and turbulence, using all available measurement levels	AERMOD is much improved over ISCST3 in this area
Use of Meteorological Data in Plume Dispersion	Stack-top variables for all downwind distances	Variables measured throughout the plume depth (averaged from plume centerline to 2.15 sigma-z below centerline; changes with downwind distance)	AERMOD treatment is an advancement over that of ISCST3; and accounts for meteorological data throughout the plume depth
Plume Dispersion: General Treatment	Gaussian treatment in horizontal and vertical	Gaussian treatment in horizontal and in vertical for stable conditions; non-Gaussian probability density function in vertical for unstable conditions	AERMOD's unstable treatment of vertical dispersion is a more accurate portrayal of actual conditions
Urban Treatment	Urban option either on or off; no other specification available; all sources must be either rural or urban	City size and population are specified, so treatment can consider a variety of urban conditions; sources can individually be modeled rural or urban	AERMOD provides variable urban treatment as a function of city population, and can selectively model sources as rural or urban
Characterization of the Modeling Domain Surface Characteristics	Choice of rural or urban	Selection by direction and month of roughness length, albedo, and Bowen ratio, providing much user flexibility	AERMOD provides the user with considerably more options in the selection of the surface characteristics

(Meister and Zwicke, 2003)

Feature	ISCST3	AERMOD	Comments
Boundary Layer Parameters	Wind speed, mixing height, and stability class	Friction velocity, Monin-Obukhov length, convective velocity scale, mechanical and convective mixing height, sensible heat flux	AERMOD provides parameters required for use with up-to-date planetary boundary layer (PBL) parameterizations; ISCST3 does not
Mixed Layer Height	Holzworth scheme; uses interpolation based upon maximum afternoon mixing height	Has convective and mechanical mixed layer height; convective height based upon hourly accumulation of sensible heat flux	AERMOD's formulation is more advanced than that of ISCST3, includes a mechanical component, and in using hourly input data, provides a more realistic sequence of the diurnal mixing height changes
Terrain Depiction	Elevation at each receptor point	Controlling hill elevation <u>and</u> point elevation at each receptor, obtained from terrain pre-processor (AERMAP) that uses digital elevation model (DEM) data	AERMOD's terrain pre-processor provides information for advanced critical dividing streamline height algorithms and uses digital data to obtain receptor elevations
Plume Dispersion: Plume Growth Rates	Based upon 6 discrete stability classes only; dispersion curves (Pasquill-Gifford) are based upon surface release experiments (Prairie Grass)	Uses profiles of vertical and horizontal turbulence (from measurements and/or PBL theory); variable with height; uses continuous growth functions rather than a discrete (stability-based) formulation	Use of turbulence-based plume growth with height dependence rather than that based upon stability class provides AERMOD with a substantial advancement over the ISCST3 treatment
Plume Interaction with Mixing Lid: convective conditions	If plume centerline is above lid, a zero ground-level concentration is assumed	Three plume components are considered: a "direct" plume that is advected to the ground in a downdraft, an "indirect" plume caught in an updraft that reaches the lid and eventually is brought to the ground, and a plume that penetrates the mixing lid and disperses more slowly in the stable layer aloft (and which can re-enter the mixed layer and disperse to the ground)	The AERMOD treatment avoids potential underpredictions suffered by ISCST3 due to its "all or nothing" treatment of the plume; AERMOD's use of convective updrafts and downdrafts in a probability density function approach is a significant advancement over ISCST3
Building Downwash	Parameterizes downwash effects based on ratio of stack height to building dimensions	Integrates the Plume Rise Model Enhancements (PRIME) into downwash calculations	AERMOD can now account for plume streamline deflection, turbulence intensities, and source locations relative to buildings thereby improving downwash calculations

(Meister and Zwicke, 2003)